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# **Evaluation of Fire Suppression Efficiency of Halon Replacements in Japan**

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## **Abstract**

"Committee on Evaluation of Fire Suppression Efficiency for Halon Replacements" in Japan discussed methods of evaluation on the fire suppression efficiency to prepare the basis of design concentration. Use of FRI cup burner was recommended to evaluate the efficiency of fire extinguishing agents in Japan by the committee.

## **Introduction**

Halon phase-out program in Japan is composed with following three main policies [1];

- (a) Ban on the new installation of halon fire extinguishing system,
- (b) Promotion of halon recycling for existing equipment, and
- (c) Employment of halon replacements.

When the candidates of halon replacement are employed as new fire extinguishing agents for total flooding system, limits of agent concentration on toxicity and fire extinguishing efficiency must be set up for realizing safe fire extinguishing. In 1993, Fire Research Institute organized "Committee on Evaluation of Toxicity for Halon Replacements." The chair person of the committee was Professor Uehara who works for Yokohama National University. The committee investigated evaluating procedures of toxicity to nominate the candidates of halon replacement and to determine the maximum design concentration of each candidate for the total flooding system [2,3].

In 1994, "Committee on Evaluation of Fire Suppression Efficiency for Halon Replacements" was established by Fire Research Institute, and studied the evaluation method of the suppression efficiency for determining the minimum of design concentrations [4]. The chair person of the committee was Professor Hirano of Tokyo University. Each committee proposed the technical guideline on evaluating procedure of toxicity or fire suppression efficiency of halon replacements in March 28, 1995, respectively. Fire Defense Agency announced the guideline on the use of halon replacements on May 10, 1995, referring to the proposals of the above two committees [5].

The paper is a report on the evaluation method of fire suppression efficiency of halon replacements proposed by Committee on Evaluation of Fire Suppression Efficiency for Halon Replacements.

## **Evaluation method of fire suppression efficiency**

The objective of evaluation of fire suppression efficiency was restricted to determine design concentration for total flooding system in the committee, because the halon replacements for the total flooding system were required most urgently and seriously in Japan in those days. In the committee, the evaluation methods were discussed from the view point of combustion science. At first, the literature on the flame extinguishing was searched for extract appropriate

evaluation methods. Then, fire extinguishing concentrations were measured by using cup burner [6] and counterflow burner [7], and peak concentrations of flammability were obtained by tubular flame burner [8]. The committee on halon phase-out program of Japan, organized by Fire Defense Agency, carried out fire extinguishing tests using large scale room fire model, independently. The objective was to obtain the information on the design concentration of potential candidates for real size compartment fires [9].

In the facilities of telecommunication, computer rooms, museums, etc., fires with diffusion flame occur more frequently than explosion accidents. Therefore, the Committee chose to evaluate the fire extinguishing efficiency by testing the extinction behavior of diffusion flame. The cup burner apparatus is only a test method standardized internationally to estimate the fire extinguishing efficiency of carbon dioxide [10]. Any other test methods have never existed internationally for evaluating the efficiency of other fire suppressants. However, the cup burner test has been widely employed as one of the most typical laboratory scale tests. Flame extinguishing concentration measured by the cup burner is used frequently as a basis for determination of a design concentration of total flooding fire extinguishing system. Thus, the cup burner method is considered one of the potential candidates of evaluation method on fire suppression efficiency of agents.

### **Flame extinguishing concentrations of cup burner**

It is known that the flame extinguishing concentration is affected by the size of cup burner [11]. To investigate whether the flame extinguishing concentration is reliable as a basis of design concentration or not, the reproducibility of the concentration was tested by measuring the flame extinguishing concentrations of halon 1301 for heptane flame using three FRI glass cup burners. The cup burner apparatus shown in Fig. 1, that has a 30 mm outer diameter cup in a chimney with an 85 mm inner diameter. The experiments were conducted under 25 °C and the atmospheric pressure, and air flow rate was adjusted at 40 liters per minute in all the tests. The flame is allowed to burn for 8 minutes before agent is added to the air stream.

The results are shown in Table 1. There is good agreement among the flame extinguishing concentrations obtained by the three apparatuses even under the small different conditions of burner setting draft chamber, cup shape, and test period. The fact means that the cup burner gives the same flame extinguishing concentration, if the measurement is carried out using same size apparatus under fixed air flow conditions [12].

The flame extinguishing concentration stayed constant, when the measurement was performed by different groups of operator as seen in Table 2. Moreover, there is good correlation between the flame extinguishing concentrations measured by the glass cup burner and the metal cup burner like Fig. 2. Therefore, use of FRI cup burners was recommended for evaluating the efficiency of fire extinguishing agents in Japan.

The flame extinguishing concentrations of new agents for various fuels have been measured and reported in the literature [6,13,14]. The up-to-date data are shown in Table 3.

### **Requirement of safety factor and extinguishing test of large scale model fire**

The flame extinguishing concentration measured by cup burner is affected by not only burner size [11], but also flow velocity of air-suppressant mixture in a chimney [15]. So, physical meaning of the concentration is ambiguous, and the conditions at fire extinction are not specified in the scenario of real fire growth. This means that the flame extinguishing concentration must be considered as the minimum concentration required for extinguishing the fire. Therefore, a safety factor is needed when a design concentration for total flooding fire extinguishing system is determined by the flame extinguishing concentration.

The design concentration for total flooding system is determined by the cup burner flame extinguishing concentration multiplied by the safety factor. However, the design concentration is not always enough to extinguish any fires. Therefore, the fire extinguishing test using large scale model fire must be required to prove the fire extinction by the design concentration.



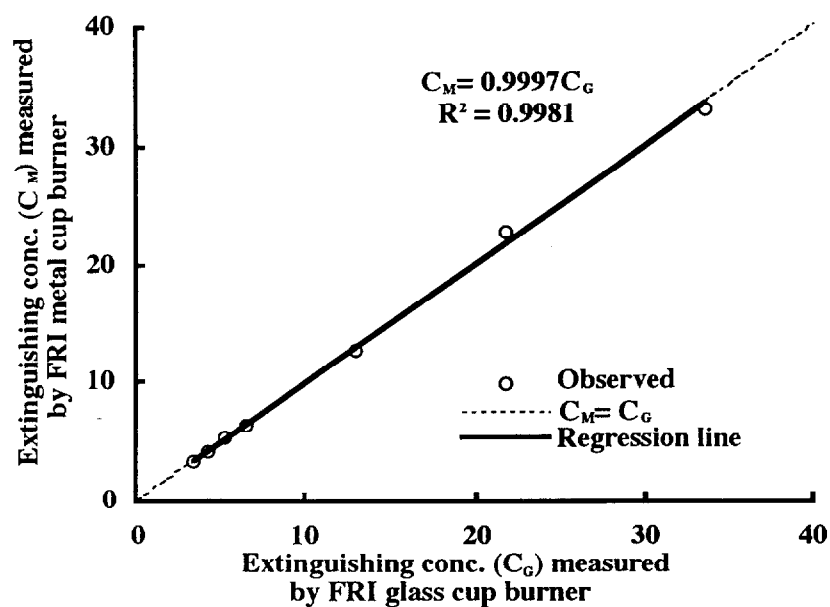
Fig. 1 FRI glass cup burner

Table 1 Extinguishing concentrations of halon 1301 for heptane flame measured by FRI glass cup burners

Test period	5 min					2.5 min		
Burner	FRI-0	FRI-1		FRI-2		FRI-0	FRI-1	FRI-2
Cup No.	1	1	2	1	2	1	2	2
Observed (%)								
1	3.37	3.48	3.18	3.37	3.37	3.22	3.22	3.41
2	3.41	3.52	3.33	3.41	3.33	3.22	3.41	3.22
3	3.29	3.44	3.44	3.41	3.29	3.14	3.37	3.33
4	3.33	3.56	3.41	3.37	3.25	3.14	3.48	3.29
5	3.33	3.56	3.44	3.44	3.41		3.29	3.37
Average (%)	3.35	3.51	3.36	3.40	3.33	3.18	3.35	3.32
Std. div.	0.046	0.052	0.110	0.030	0.063	0.046	0.102	0.073

**Table 2** Flame extinguishing concentrations of halon 1301 for heptane flame measured by different operator groups

Groups	Observed data (%)					Average	Std. div.
A	3.42	3.46	3.42	3.35	3.39	3.41	0.041
B	3.36	3.40	3.36	3.51	3.29	3.38	0.081
C	3.44	3.40	3.30	3.37	3.44	3.39	0.059
D	3.44	3.30	3.37	3.33	3.37	3.36	0.053
E	3.33	3.30	3.40	3.40	3.44	3.37	0.057
F	3.37	3.44	3.56	3.37	3.44	3.44	0.078
G	3.42	3.46	3.42	3.35	3.39	3.41	0.041



**Fig. 2** Comparison of flame extinguishing concentrations measured by glass cup burner and metal cup burner

**Table 3 Flame extinguishing concentrations measured by FRI glass cup burner**

Agent	Fuels								
	heptane	octane	decane	undecane	dodecane	methanol	ethanol	benzene	toluene
Halon 1301	3.4	3.4	3.9	3.8	3.7	7.8	4.3	2.4	2.3
FC-3-1-10	5.3					8.0	6.9	3.4	3.6
HFC-227ea	6.6					9.4	8.2	4.8	4.6
HFC-23	12.9					19.0	16.0	10.6	9.7
N <sub>2</sub>	33.6	33.8	33.9	33.3	33.5	43.5	36.8	30.9	25.7
Ar	43.3								
CO <sub>2</sub>	22.0		23.4	23.5	22.8	29.3	24.3	20.2	16.9
IG541	35.6								
IG505	25.9								

### Consistency of flame extinguishing concentrations measured by FRI cup burner

The flame extinguishing concentration measured under the fixed conditions showed good reproducibility enough to use a basis for determining a design concentration. Since the design concentration has to be changed by characteristic of combustibles, it requires consistency of the flame extinguishing concentrations measured by the cup burner.

Let's assume that inert gases act only as heat sink individually in flame, and that the flame extinction occurs when the flame temperature decreases and reaches at a certain threshold value. Then, the following expression is derived for the flame extinguishing concentration  $C_M$  of any mixture M of inert gases by simple thermodynamic consideration [16].

$$1 / C_M = \sum_{j=1}^n X_j / C_j. \quad (1)$$

In Eq. (1),  $n$  is number of components in the inert gas mixture.  $X_j$  and  $C_j$  denote mole fraction and flame extinguishing concentration of  $j$ th component, respectively. The equation is similar to the famous formula for calculating the flammability limits of any mixture of combustible gases [17].

Since the flame extinguishing concentrations of nitrogen, argon, carbon dioxide, and inert gas mixtures, IG541 and IG505, for heptane are shown in Table 3, we can confirm the verity of the Eq. (1). The calculated flame extinguishing concentrations of IG541 and IG505 mixtures are compared with the observed values in Table 4. Here, the calculation was carried out using the flame extinguishing concentrations of nitrogen, argon, and carbon dioxide in Table 3, and the composition of the mixtures listed in Table 4. The estimated values agree well with the observed value within 3 % in relative difference to mean value. The fact suggests that the relation of Eq. (1) is correct for the flame extinguishing concentration of any inert gases, and at the same time, there is no contradiction in the flame extinguishing data measured with FRI cup burner.

To confirm the assumptions for Eq. (1), adiabatic flame temperature was calculated for the heptane diffusion flame diluted with nitrogen, argon, carbon dioxide, IG541, or IG505 just under the flame extinction condition. The calculated temperature and mole number of main combustion products generated per unit mole of fuel are listed in Table 5, that shows also the flame extinguishing concentrations measured by FRI cup burner. All the calculated adiabatic flame temperatures agree well, and the mole numbers of each main product are also nearly equal

to each other, except the case of CO production. In the case where carbon dioxide or IG505 is added, CO production becomes twice. However, the CO concentration in burned gas is low enough, so it can change only 0.4 % or less of the total heat capacity of combustion products. The results mean that the assumptions in Eq. (1) are valid for the flame extinction of the FRI cup burner by inert gases. At the same time, this is a proof of the consistency on the flame extinguishing concentrations reported in Table 3.

**Table 4 Comparison of calculated flame extinguishing concentrations (%) of IG541 and IG505 mixtures for heptane flame with observed values**

Mixture	Flame ext. conc. (%)		Compositions of mixture (%)		
	Calc.	Obs.	N <sub>2</sub>	Ar	CO <sub>2</sub>
IG541	35.6	35.6	51.5	41.6	6.9
IG505	26.6	25.9	50.0	0.0	50.0

**Table 5 Production of stable species (moles per unit mole fuel) and temperature of heptane diffusion flame at extinction by inert gas mixtures**

Products	Inert Gases				
	N <sub>2</sub>	Ar	CO <sub>2</sub>	IG541	IG505
H <sub>2</sub> O	7.97	7.96	7.97	7.97	7.97
H <sub>2</sub>	0.02	0.03	0.02	0.02	0.02
CO <sub>2</sub>	6.92	6.91	6.80	6.89	6.82
CO	0.08	0.09	0.20	0.11	0.18
Flame Temp.(K)	1820	1835	1849	1836	1858
Ext. Conc. (%)	33.6	43.3	22.0	35.6	25.9

## Conclusion

In Japan, the FRI cup burner is used to evaluate the fire suppression efficiency of halon replacements. The cup burner is a potential apparatus for evaluation of fire suppression efficiency. It gives the same flame extinguishing concentration, if the measurement is carried out using same size apparatus under fixed air flow conditions.

It was suggested by thermodynamic consideration that flame extinguishing concentration of any mixture of inert gases is represented as a simple relation of mole fraction and flame extinguishing concentration of components in the inert gas mixture. The flame extinguishing concentrations of the inert gas mixtures for heptane flame were observed and compared with the estimated values. There was good agreement between both the values, and the flame extinguishing concentrations measured by the cup burner are consistent. At the same time, this is a proof of the consistency on the flame extinguishing concentrations in the paper.

## Reference

- [1] Prevention Section, Fire Defense Agency, 1990 Annual Report of Committee on Halon Phase-Out (March, 1991) (in Japanese)
- [2] Fire Research Institute, 1993 Annual Report of Committee for Evaluation on Toxicity of Halon Replacements (March, 1994) (in Japanese)
- [3] Fire Research Institute, Final Report of Committee for Evaluation on Toxicity of Halon Replacements (Sept., 1995) (in Japanese)
- [4] Fire Research Institute, Final Report of Committee for Evaluation on Fire Suppression Efficiency of Halon Replacements (Dec., 1995) (in Japanese)
- [5] Suzuki, K., Treatment Procedure on Fire Extinguishing Gas systems as Halon Replacement, Kasai (Journal of Japan Association for Fire Science and Engineering), 45 (6), 1-6 (1995) (in Japanese)
- [6] Inoue, Y., Saito, N., Saso, Y., and Ogawa, Y., Evaluation of Fire Suppression Efficiency and Practical Applicability of Halon Replacements, Report of Fire Research Institute of Japan, No. 79, pp. 1-7 (1995) (in Japanese)
- [7] Saso, Y., Saito, N., Liao, C., Ogawa, Y., and Inoue, Y., Evaluation of Fire Suppression Efficiency of Fire-Extinguishing Agents using Counterflow Diffusion Flame, Report of Fire Research Institute of Japan, No. 78, pp. 42-50 (1994) (in Japanese)
- [8] Saito, N., Saso, Y., Liao, C., Ogawa, Y., and Inoue, Y., Flammability Peak Concentrations of Halon Replacements and Their Function as Fire Suppressant, ACS Symposium Series **611**, pp. 243-257, American Chemical Society (1995)
- [9] Prevention Section, Fire Defense Agency, 1993 Annual Report of Committee on Halon Phase-Out (March, 1994) (in Japanese)
- [10] ISO 6183, Fire protection equipment - Carbon dioxide extinguishing systems for use on premises - Design and installation, (1991)
- [11] Saso, Y., Saito, N., and Iwata, Y., Scale Effect of Cup Burner on Flame-Extinguishing Concentrations, Fire Technology, **29**, pp. 22-33 (1993)
- [12] Saito, N., Saso, Y., Ogawa, Y., Inoue, Y., Sakei, R., and Otsu, Y., Improvement on Reproducibility of Flame Extinguishing Concentration Measured by Cup Burner Method, Proc. Halon Options Technical Working Conference, pp. 299-309, Albuquerque, NM (May, 1995)
- [13] Sakei, R., Saito, N., Saso, Y., Ogawa, Y., and Inoue, Y., Flame Extinguishing Concentrations of Halon Replacements for Flammable Liquids, Report of Fire Research Institute of Japan, No. 80, pp. 36-42 (1995) (in Japanese)
- [14] Saito, N., Sakei, R., Saso, Y., and Ogawa, Y., Some Problems on Measurement of Flame Extinguishing Concentration for High Flash Point Liquid Fuels, Proc. 33th Japanese Symposium on Combustion, pp. 539-541, Combustion Society of Japan (1995) (in Japanese)
- [15] Bajpai, S. N., An Investigation of the Extinction of Diffusion Flames by Halons, J. Fire & Flammability, **5**, pp. 225-267 (1974)

[16] Saito, N., Ogawa, Y., Saso, Y., Liao, C., and Sakei, R., Flame Extinguishing Concentrations and Peak Concentrations of N<sub>2</sub>, Ar, CO<sub>2</sub>, and Their Mixtures for Hydrocarbon Fuels, Submitted to Fire Safety J.

[17] Coward, H. F. and Jones, G. W., Limits of Flammability of Gases and Vapors, pp. 6, Bureau of Mines Bull. 503 (1952)

### ***Discussion***

William Grosshandler: Could you explain what the standard procedure is in Japan once you have the efficiency. How does one actually go about the design?

Naoshi Saito: In Japan they use the cup burner concentration for the design concentration. Then we multiply an appropriate safety ratio by that flame extinguishing concentration. How to set this safety ratio is left totally to the discretion of the designer of the apparatus. However, if you just stop there, there is always some fear that it might not be able to extinguish the fire so after designing it, you have to do a large scale room experiment.

Richard Gann: Several years ago, we experimented with replacing the heptane by a stick of PMMA to make the procedure simpler. Have you thought of something like that?

Naoshi Saito: Our purpose is to extinguish all the flammable things in the room or in the space. In our opinion, PMMA cannot represent everything which is flammable in the room or space.